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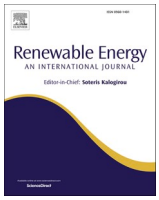

Optimal design and techno-economic feasibility of PV systems integrated with residential EV charging for Omani households

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ABSTRACT

Integrated photovoltaic (PV) systems with residential electric vehicle (EV) charging stations are essential for advancing EV adoption, reducing carbon emissions, and promoting sustainability in the building and transportation sectors. However, their widespread adoption hinges on their techno-economic feasibility. This research investigates the optimal design and techno-economic feasibility of on-grid PV systems integrated with EV charging stations for Omani households, considering local electricity tariffs for purchasing and selling power to the utility grid. A simulation-optimization approach, utilizing HOMER Grid software, is applied to optimize the system configuration and EV charging schedule, minimizing the Net Present Cost (NPC) while adhering to system constraints. A baseline scenario, based on a household load of 54 MWh/year and Oman's current Inclining Block Rate (IBR) and Bulk Supply (BS) tariffs, reveals that reliance on the utility grid is the most cost-effective solution, with an NPC of $27.5k and annual CO_2 emissions of 26.4 tons. A factorial design experiment evaluated the effects of IBR and BS tariffs, capital cost, and load profile on PV sizing and economics. Results show that under current tariff structures, reliance on the utility grid remains most cost-effective. However, factorial analysis revealed that increases in IBR and BS tariffs (simulating future tariff reforms) significantly increase the optimal PV system size and reduce the NPC, particularly when combined with reduced capital costs. These findings underscore the dominant role of tariff policy and capital cost in determining feasibility, with load profile having a relatively minor effect. They also highlight the conditions under which PV systems integrated with EV charging stations could become viable for Omani households, providing quantitative evidence to inform tariff reforms and capital cost subsidies aligned with Oman Vision 2040.

1. Introduction

Electricity is vital to modern life, from illuminating homes at night to powering machinery and enabling global connectivity. Oman has made significant progress in providing electricity access, with nearly 100 % of its population having access to this essential resource, according to recent reports. In 2022, the annual per capita electricity consumption in Oman averaged around 8.2 MWh per year (see Fig. 1) [1]. Moreover, the total electricity supply has steadily increased over the past seven years, from 2017 to 2023 (see Fig. 2) [2]. The country's electricity supply is primarily dependent on domestically produced natural gas and oil products. Although fossil fuels still dominate electricity generation (see Fig. 3), Oman is actively working to diversify its energy sources to ensure energy security and sustainability.

The country aims to reduce its dependence on fossil fuels by implementing energy efficiency measures and integrating renewable energy (RE) sources into its energy mix. Specifically, Oman Vision 2040 has set a target to meet 20 % of electricity demand with renewable energy by 2030, and 35–39 % by 2040 [3].

The building sector accounted for 80 % of energy demand in 2021, contributing 13.5 Mt CO_2 emissions in the power sector, which represents 15 % of Oman's overall emissions [4]. As a result, the country has set a national strategy to reduce total energy demand by 30 % by 2050. This strategy focuses on promoting solar panel installations, improving the energy efficiency of air conditioning units and appliances, and encouraging the switch to LED lighting [4]. Notably, residential

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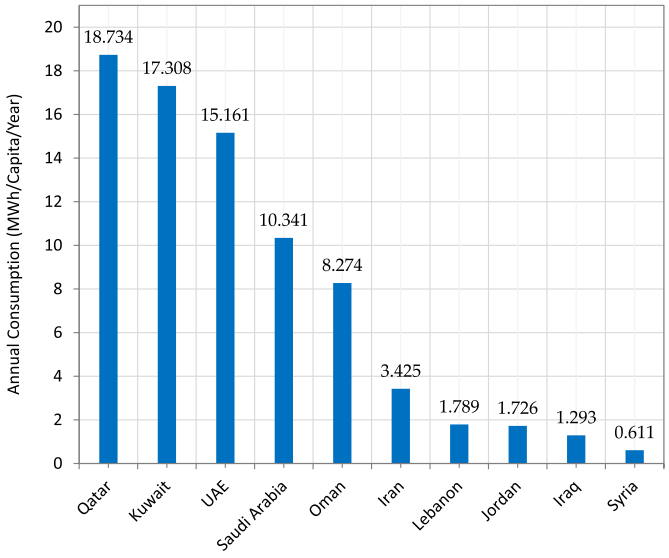


Fig. 1. Annual per capita electricity consumption, regional ranking, 2021 [1].

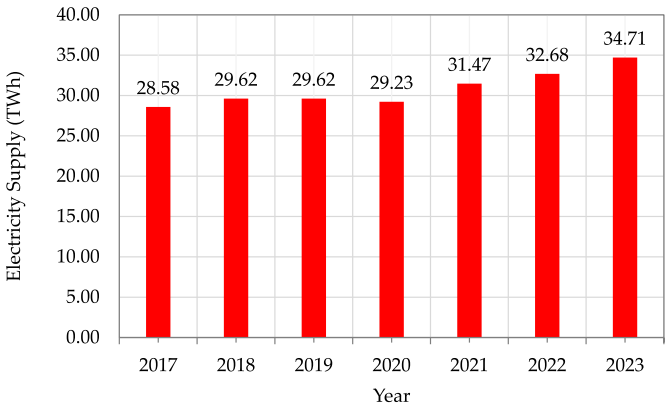


Fig. 2. Total electricity supply (TWh) from 2017 to 2023 [2].

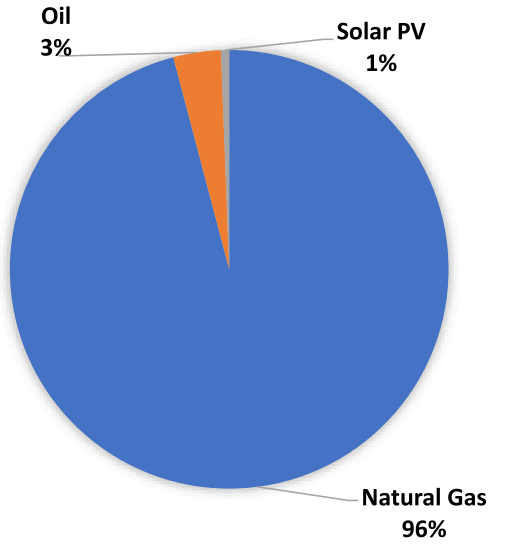


Fig. 3. Sources of electricity generation in Oman (%), 2021 [1].

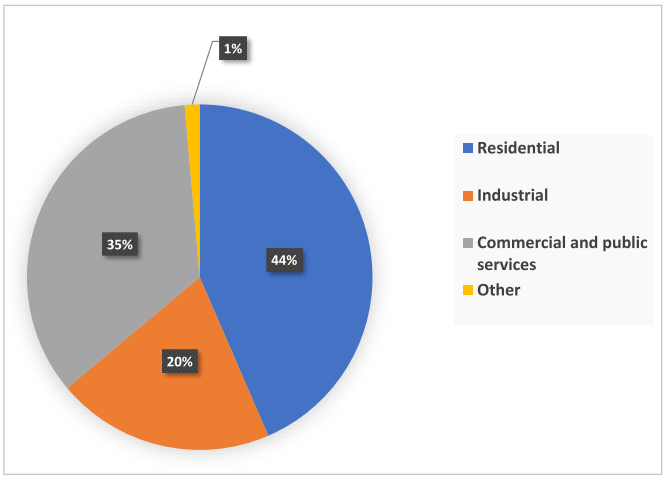


Fig. 4. Electricity final consumption by sector in Oman (%), 2022 [4].

customers were the largest consumers of electricity in Oman, accounting for 45 % of the total electricity demand in 2021 [4], as depicted in Fig. 4. In response, the government launched the "Residential PV Initiative" to encourage Omani households to adopt solar PV system. The initiative aims to increase the share of RE in the residential sector's electricity mix, aligning with Oman's broader goal of transitioning towards a more sustainable and diversified energy portfolio. Installing solar panels could help manage electricity costs and reduce bills for the Omani households. An incentive mechanism has been introduced to allow households to benefit from the electricity generated by solar panels, both for self-consumption and for exporting surplus energy to the grid under the Bulk Supply Tariff [5]. The electricity tariffs, including the Bulk Supply Tariff, applied in Oman will be explained in the system description section of this paper.

The transport sector in Oman emits 15.9 million metric tons of carbon dioxide annually, accounting for 18 % of the country's total emissions in 2021 [6]. Residential vehicles contribute to approximately 60 % of these emissions, with around 1.3 million cars comprising about 87 % of the transport fleet. Under a business-as-usual scenario, these emissions are projected to increase by 41 % by 2050 due to population growth [6]. In response to similar trends globally, most countries have begun transitioning to electric vehicles (EVs) as part of their strategies to reduce carbon emissions and promote sustainable transportation [6]. However, widespread EV adoption faces significant challenges, including high initial costs, insufficient charging infrastructure, and concerns about range and charging times [7]. Moreover, the increased electricity demand for EV charging could strain traditional power generation capacity. If this demand is met using non-renewable energy sources, the environmental benefits of EVs could be diminished. Therefore, it is crucial to ensure that the shift to EVs is accompanied by the generation of renewable energy to sustain both environmental goals and energy security [8].

The integration of EV charging stations with the residential sector offers significant benefits for EV owners, with enhanced convenience and cost-effectiveness being key advantages [9]. This integration also plays a crucial role in promoting the widespread adoption of electric vehicles, aligning with clean transportation goals. While EVs may increase household electricity consumption, their impact can be managed through smart charging practices, integration with renewable energy sources, and grid load management strategies. Additionally, charging EVs with electricity generated from renewable sources, such as solar PV systems, presents a significant opportunity to reduce carbon emissions and promote environmental sustainability [10].

Integrating EV charging infrastructure with residential buildings is a critical step towards achieving cleaner, more sustainable energy systems while supporting the widespread adoption of electric vehicles. However,

despite their benefits, several operational challenges must be addressed for widespread EV adoption [11]. Furthermore, consumers remain hesitant to transition from traditional vehicles to EVs. By the end of 2022, electric vehicles accounted for only 8 % of the U.S. automobile market, and the country continues to face challenges in promoting widespread EV adoption [11]. Therefore, it is essential to understand how residential customers perceive electric vehicles and the potential barriers they may face. This can be achieved through technical and economic studies of electric vehicle charging systems in relation to household electricity consumption.

Although the adoption of EVs in Oman may have been relatively modest compared to some other regions, there are clear signs of progress and growing momentum toward cleaner and more sustainable transportation options [12]. In 2024, there was a 300 percent increase in the number of EVs in Oman compared to 2023. With continued support from government policies, infrastructure investments, and public awareness campaigns, the adoption of EVs in Oman is expected to grow in the coming years. For the residential sector, subsidized electricity pricing makes home charging an attractive option compared to the running costs of internal combustion engine vehicles [12]. However, it is necessary to investigate the techno-economic feasibility of integrating RE systems with EV charging stations at the household level. Such studies can promote the adoption of sustainable solutions and identify the key factors that will facilitate their deployment and implementation.

Previous studies have discussed integrated RE systems for EV charging [13]. On the other hand, Pamidimukkala et al. [11] introduced the impact of barriers on EV adoption. Their results revealed that the main barriers were the high purchase price of EVs and the lack of sufficient public charging stations. This underscores the importance of conducting techno-economic studies to develop EV charging systems for residential use. An extensive survey, as presented in Table 1, has been conducted in this study to review previous works addressing the techno-economic assessment of EV charging stations for private home usage. The table also provides a detailed comparison of previous research articles and this paper, highlighting the contribution of our paper. It summarizes previous studies on renewable energy (RE) systems for EV charging, including their applications, renewable resources, home charging, utility bill savings, Inclined Block Rate (IBR) tariff

Table 1
Detailed extensive survey and comparison of previous studies on RE systems for EV charging highlighting the contribution of our paper.

References	Country	Technologies	Renewable Resources	Application	Home charging	Utility bill saving	IBR Tariff Effect	BS Tariff Effect	Load Profile Effect	Capital cost Effect
[14]	Australia	PV-grid	Solar	Residential building	✔	✔	X	X	X	X
[15]	Malysia	PV-grid-battery	Solar	Residential building	✔	✔	X	X	X	X
[16]	Australia	PV-grid	Solar	University campus	X	X	X	X	X	X
[17]	China	PV-on grid-off grid	Solar	Office building	X	X	X	X	X	X
[18]	Netherlands	PV- grid	Solar	Work place	X	X	X	X	X	X
[19]	China	PV- grid	Solar	Parking station	X	X	X	X	X	X
[20]	India	PV- grid	Solar	Charging station	X	X	X	X	X	X
[21]	Vietnam	PV-battery-grid	Solar	Three big cities	X	X	X	X	X	X
[22]	Iran	PV-grid	Solar	Five charging station	X	X	X	X	X	X
[23]	US	PV- wind turbine-grid	Solar-Wind	Commercial charging stations in parking lots	X	X	X	X	X	X
[24]	UK	PV-wind turbine-storage system	Solar- wind	charging stations	X	X	X	X	X	X
[25]	Egypt	PV-wind turbine-storage system	Solar- wind	Charging station	X	X	X	X	X	X
[26]	–	Wind turbine-battery-grid	Wind	Charging station	X	X	X	X	X	X
[27]	Morocco	PV-wind turbine-Battery-grid	Solar- Wind	Supermarkets in three cities	X	X	X	X	X	X
[28]	Spain	PV-wind turbine-diesel generator- Battery-grid	Solar- Wind	Public Charging stations	X	X	X	X	X	X
[29]	China.	PV-wind turbine- Battery	Solar- Wind	Charging stations at five different locations	X	X	X	X	X	X
[30]	Bangladesh	Biogas generator	Biomass	Charging station	X	X	X	X	X	X
[31]	Bangladesh	Biogas generator-PV-battery	Biomass-solar	Charging station	X	X	X	X	X	X
[32]	Bangladesh	PV- wind turbine-grid	Solar-wind	International Airport	X	X	X	X	X	X
[33]	India	PV-Wind turbine-Fuel cell	Solar-Wind	Charing station	X	X	X	X	X	X
[34]	Saudi Arabia	PV-Wind turbine- Battery	Solar-Wind	Residential house	✔	X	X	X	X	X
[35]	Qatar	CPV-Wind turbine-electrolyzer- fuel cell-battery- diesel generator	Solar-Wind	Charging station	X	X	X	X	X	X
[36]	India	PV-off/ongrid	Solar	Community	X	X	X	X	X	X
[37]	Ethiopia	PV-Wind turbine-Diesel-Battery	Solar- Wind	Charging stations	X	X	X	X	X	X
[38]	Malysia	PV-Wind turbine- fuel cell- battery-grid	Solar- wind	Charging stations	X	X	X	X	X	X
[39]	Brunei	Grid	–	Charging stations	X	X	X	X	X	X
[40]	Nigeria	PV-wind-Diesel-battery	Solar	Residential community	X	X	X	X	X	X
[41]	Pakistan	PV-grid	Solar	Charging station	X	X	X	X	X	X
[42]	Oman	PV-baterry-wind- grid	Solar-wind	Charging station	X	X	X	X	X	X
Our Paper	Oman	PV-grid	Solar	Residential charging station	✔	✔	✔	✔	✔	✔

effects, Bulk Supply (BS) tariff effects, load profiles, and capital costs.

In all the aforementioned studies (Table 1), very few have discussed EV charging stations specifically for private home charging. Moreover, the previous studies their conclusions are often specific to certain cases and locations, limiting their generalizability. Further research is needed to address this gap and evaluate the applicability of these findings across diverse contexts and scenarios.

Oman's electricity profile—marked by high per capita consumption and a residential sector that accounts for nearly half of national demand—underscores the urgent need for sustainable, household-level energy solutions. As the country moves toward its Vision 2040 and Net Zero 2050 targets, rising electricity demand from growing electric vehicle adoption, particularly through home-based charging, is expected to intensify grid pressure and carbon emissions in a system still largely dependent on fossil fuels. At the same time, Oman's abundant solar resources, cost-reflective tariff mechanisms, and typical villa-style architecture—with ample rooftop and garden space—create favorable conditions for deploying distributed rooftop photovoltaic (PV) systems. Integrating these systems with residential EV charging infrastructure presents a timely opportunity to reduce grid dependency, enhance energy autonomy, and advance national decarbonization goals. However, the techno-economic feasibility of such integration remains underexplored in Oman, particularly under realistic residential conditions that reflect actual demand profiles, tariff structures, and capital costs. This study addresses that gap by employing a simulation-optimization framework using HOMER Grid to determine the cost-effective design of a grid-connected PV-EV system for a typical household in Muscat, evaluating multiple PV sizing scenarios and key economic factors to inform future energy policy and deployment strategies.

In this paper, a simulation-optimization approach has been employed to determine the optimal configuration of a PV system integrated with an EV charging station to meet the energy demand of an Omani household at the minimum NPC. The framework is structured into two key phases: the development of a simulation model using HOMER Grid software and the optimization of the system design and EV charging schedule. A comprehensive simulation model is developed using HOMER Grid software, which incorporates Omani electricity tariffs, household load profile, and EV charging demand. The optimization model for system design and operation has been formulated and presented, and the optimal solution is obtained through HOMER Grid's internal optimization algorithm, after tuning its parameters. The simulation model is then used to search for the optimal solution, guided by this algorithm, ensuring the system's performance is optimized to minimize costs while satisfying energy demands and other constraints. This approach provides a solid framework for assessing the techno-economic feasibility of integrating a PV system with an EV charging station, ultimately identifying the most cost-effective configuration to meet the household's energy needs. This approach can also be adopted for other cases, either in Oman or beyond.

The results indicate that, based on the current IBR and BS tariffs in Oman and the load profile considered in this paper, the base system (utility grid) can serve the load at the lowest cost. To further analyze the optimal configuration of PV systems for Omani households, a factorial design experiment was conducted to investigate the impact of various factors, including load profile, IBR tariff, BS tariff, and capital cost, on the system size and other techno-economic performance metrics. The results from this experiment revealed that the optimal design favors larger system sizes when the BS tariff is increased and the capital cost is decreased. In contrast, the load profile was found to have minimal impact on the system size, suggesting that economic factors hold greater significance in determining the effectiveness of PV system integration. Moreover, the interactions between these factors were examined to draw insightful conclusions and provide recommendations for suitable policies aimed at facilitating the widespread adoption of PV systems among Omani households. These findings emphasize the importance of adjusting tariff structures and reducing capital costs to encourage larger PV installations, thereby supporting both economic viability and environmental sustainability in the region.

This research makes a significant contribution by addressing the underexplored integration of renewable energy systems with household EV charging in Oman, a region with abundant solar energy potential. The study introduces a simulation-optimization approach for designing an optimal grid-connected solar PV system integrated with EV charging, and evaluates its techno-economic feasibility by considering local tariffs, energy consumption patterns, and economic factors. The findings provide valuable insights for policymakers, utilities, and residential consumers seeking sustainable energy solutions, and offer a scalable, adaptable model that can be applied to other regions with similar energy and economic contexts. Furthermore, the research serves as a benchmark for future studies, aiding in the advancement of renewable energy integration with EV charging infrastructures globally.

This paper is organized as follows. Section 2 provides a description of the energy system, including its key components. Section 3 outlines the simulation-optimization approach used to determine the optimal system configuration. Section 4 presents the results analysis, including the optimal system configuration and techno-economic feasibility. Section 5 covers factorial analysis, investigating the impact of various factors on system performance. Finally, Section 6 concludes the paper and offers directions for future research.

2. System description

This section provides a detailed description of the proposed grid-connected PV system integrated with an EV charging station for residential applications in Oman. It outlines the system's key components, including rooftop PV panels, an inverter, an electricity meter, and the charging station (see Fig. 5). The section also highlights Oman's electricity tariffs, where households without PV systems are charged under the IBR tariff, while those with PV installations benefit from the Bulk Supply tariff. Additionally, it discusses the various costs associated with the system, including both capital and operational costs, which contribute to the Net Present Cost (NPC). Finally, the section addresses the challenge of optimally designing and operating this integrated system, emphasizing the goal of minimizing the NPC while meeting household energy demands and supporting EV charging within the context of Oman's energy landscape.

2.1. Main system components

The photovoltaic array is crucial for converting solar radiation into electricity, with its performance determined by key factors such as capacity, which is based on the array's size and panel efficiency, and overall efficiency, which dictates how much solar energy is converted into useable electricity. The energy generated by the PV system depends on the capacity of the PV array and the available solar irradiance at a given time. The amount of electricity produced varies based on these factors, and the resulting PV system output at any given time is governed by the relationship described in Equation (1), which reflects the core physical principles embedded within HOMER Grid's internal simulation engine. While monthly average hourly data were used as model inputs, HOMER Grid interpolates these into synthetic hourly profiles to apply this relationship throughout the simulation period.

$$E_{PV}(t) = P_r \cdot dr \cdot \left(\frac{S}{S_{ref}}\right) \cdot \left(1 + \alpha \cdot \left(T - T_{ref}\right)\right) \quad (1)$$

where:

P_r the rated capacity of the PV array, meaning its power output under standard test conditions [kW]
dr the PV derating factor [%]
S the solar radiation incident on the PV array in time step t [kW/m^2]

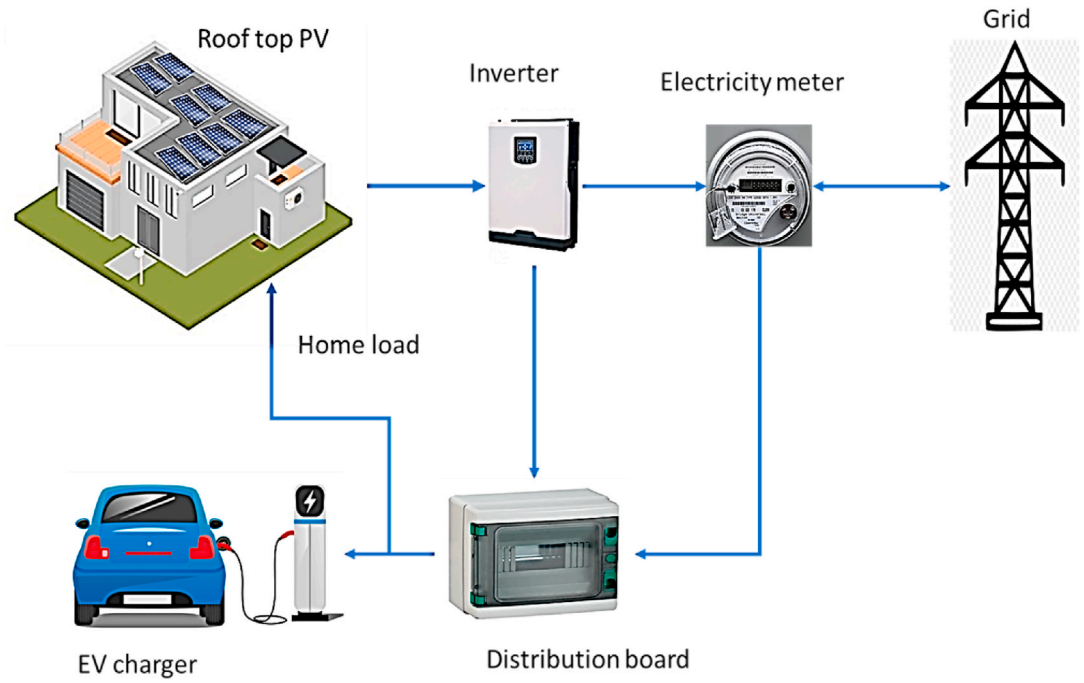


Fig. 5. Schematic drawing of the grid connected PV system for residential baseline load and EV charging station.

S_{ref} the incident radiation at standard test conditions [1 kW/m^2]
α the temperature coefficient of power [%/°C]
T the PV cell temperature at the time step t [°C]
T_{ref} the PV cell temperature under standard test conditions [25 °C]

The inverter converts the DC electricity generated by the solar panels into AC electricity, which can be exported to the grid or used to serve the load. The inverter should be sized to match the capacity of the solar panels, and its input rating should never be lower than the total wattage of the connected load.

The utility grid is interconnected and operates 24/7, with no standby charges. The carbon emission rate for the grid is set at 489.9 g CO_2/kWh. The utility supplies the load based on IBR tariff, which is detailed in section 2.1.3.

2.2. Household EV charging energy demand

Household energy demand in Oman is significantly influenced by the country's hot climate, with air conditioning accounting for the largest share of electricity consumption, especially during the summer months. Seasonal variations lead to higher energy use in summer as temperatures frequently exceed 40 °C, while demand decreases in winter. In addition to cooling systems, other appliances like electric water heaters and high-energy devices contribute to baseline household consumption. With the increasing adoption of electric vehicles, energy demand is further rising due to the additional load from EV charging. The mismatch between solar energy production and household demand, particularly during late afternoons and evenings, necessitates energy imports from the grid. Overall, these factors create high and fluctuating energy consumption patterns, highlighting the importance of integrating energy-efficient technologies and optimizing the use of PV systems. As such, the household total energy demand includes both baseline consumption and energy for EV charging can be calculated as follows:

$$E_d(t) = E_{hl}(t) + E_{ev}(t) \quad (2)$$

where:

- $E_{hl}(t)$: is the baseline electricity consumption of household at time t (kWh)
- $E_{ev}(t)$: is the energy required to charge the EV at time t (kWh)

Details on the energy consumption patterns of the load appliances and EV charging will be discussed in the results section.

2.3. Tariff structure

The IBR tariff is applied to Omani households for purchasing electricity from the grid, encouraging energy conservation by increasing electricity rates as consumption rises. It is structured in blocks, with higher rates applied to consumption beyond the initial block's limit. The tariff is structured into three blocks, with varying rates based on the number of accounts held. For primary accounts, the cost starts at 14 Baisa per kWh for consumption up to 4000 kWh/month, rising to 18 Baisa for usage between 4001 and 6000 kWh, and reaching 32 Baisa for consumption exceeding 6000 kWh. For additional accounts, rates are higher, beginning at 22 Baisa for up to 4000 kWh. This tiered pricing structure incentivizes households to manage their energy use effectively, promoting energy efficiency and potentially leading to a shift towards renewable energy sources as consumers seek to reduce reliance on the grid and mitigate costs associated with high consumption. The specific costs for each block are outlined in Table 2.

The bulk supply tariff in Oman, detailed in Table 3, governs the export of excess electricity generated by PV systems to the grid. Under

Table 2
Inclining block rate tariffs for electricity supply to residential households in Oman (2024) [43].

Category	Tariff Structure (kWh/Month)	Tariff Rate (Baisa[a]/kWh)
Primary Account (Two accounts or less)	0–4000	14
	4001–6000	18
	More than 6000	32
Additional accounts (More than two accounts)	0–4000	22
	4001–6000	26
	More than 6000	32

[a] 1 OMR = 1000 Biasa = 2.6 USD in August 2024.

Table 3
Surplus solar energy export tariff in Oman (Baisa[a]/kWh) [5].

Time Period	Day Type	Time Range	January–March	April	May–June	July–August	Sept–Oct	Nov–Dec
Night Peak	Weekday	00:00 to 02:59	12	32	48	17	20	12
Night Peak	Weekend	00:00 to 02:59	12	24	32	15	17	12
Night Peak	All Days	03:00 to 09:59	12	19	28	14	15	12
Day Peak	Weekday	10:00 to 15:59	12	24	45	14	17	12
Day Peak	Weekend	10:00 to 15:59	12	19	26	14	17	12
Day Peak	All Days	16:00 to 19:59	12	19	27	14	17	12

[a] 1 OMR = 1000 Biasa = 2.6 USD in August 2024.

this tariff structure, when a residential PV system produces more electricity than is required for household consumption, the surplus energy can be sold back to the grid at the designated BS tariff rate. This arrangement incentivizes the adoption of RE sources by allowing households in Oman to capitalize on surplus energy production, thereby contributing to overall energy efficiency and sustainability within the national grid. The BS tariff varies based on time periods and day types, with distinct rates applicable for night and day peak hours during weekdays and weekends. This variability reflects the demand fluctuations throughout the day, encouraging consumers to optimize their energy production and consumption. The specific rates for the surplus solar energy export are outlined in Table 3.

The monthly electricity bill under the BS tariff applies to energy systems that incorporate both imported and exported electricity. This model is relevant for households with grid-connected photovoltaic systems, where surplus energy can be sold back to the grid. The total monthly electricity bill is calculated as the difference between the cost of imported electricity and the credit for exported electricity (Eq. (3)). In other words, the household is charged for the electricity imported from the grid and credited for the electricity exported back to the grid. Equation (4) represents the total cost of importing electricity as the sum of the product of the unit cost and the amount of electricity imported at each time step throughout the billing period. In the IBR case, the import charge is calculated at the end of each month from the total kilowatt-hours imported, using the block thresholds and rates in Table 2. We therefore do not assign an hour-by-hour price within the month; the effective unit price is the one implied by the final block reached. By contrast, under a time-of-use tariff the unit price changes by time of day (and season) and is applied directly to each time interval. Equation (5) calculates the credit received for exporting electricity by summing the value of exported electricity across all time intervals within the billing period.

$$\textit{The monthly electricity bill} = \textit{cost of imported eletricity} - \textit{cost of exported eletricity} \tag{3}$$

$$\textit{cost of imported eletricity} = \sum_{t=1}^{T} C_{grid}\,(t).E_{gi}(t) \tag{4}$$

$$\textit{cost of exported eletricity} = \sum_{t=1}^{T} C_{sell}(t).E_{ge}(t) \tag{5}$$

where:

- $C_{grid}\,(t)$: is the unit cost of imported grid electricity at time (t) (OMR/kWh).
- $E_{gi}(t)$: is the energy imported from the grid at time (t) (kWh).
- $C_{sell}(t)$ is the unit cost of export electricity (Table 3) from solar system at time (t) (OMR/kWh).
- $E_{ge}(t)$ is the energy exported to the grid at time (t) (kWh).
- T is the total number of time intervals considered for billing period.

2.4. System costs

The net present cost (NPC) of the system comprises several key components: the capital cost, which covers installation expenses; operating and maintenance (O&M) costs, which are incurred annually; and replacement costs, which account for major upgrades or replacements over the system's lifetime. Additionally, revenues generated by the system, such as earnings from excess electricity sold back to the grid, are factored in. The NPC is calculated using Eq. (6) that considers all these components to assess the total cost over the project's lifetime.

$$NPC = \left(C_{cost} + \sum_{i=1}^{n} \frac{O_{m,i} + R_{c,i} - Rev_i}{(1+r)^i} \right) \tag{6}$$

where:

C_{cost}: Capital Cost, $O_{m,i}$: Operating & Maintenance Cost at year i, $R_{c,i}$: Replacement Cost at year i, Rev_i: Revenue earned at year i, r: Real discount rate, and n: Number of years (project life time).

2.5. Design and operational decisions

The problem at hand involves designing and operating a grid-connected PV integrated with EV charging station for Omani households, focusing on minimizing NPC. This entails determining the optimal PV system size, which includes selecting the appropriate number of panels and specifying the inverter size to ensure efficient energy conversion that meets the household's energy demands and available roof space. Additionally, formulating an optimal EV charging schedule is essential to maximize the utilization of electricity generated by the PV system while reducing reliance on the grid. These decisions must also consider the household's budget constraints to support the initial system costs and ensure a practical and cost-effective solution that aligns with broader sustainability objectives.

3. Simulation-optimization approach

This research employs a simulation-optimization approach to determine the optimal design of the energy system configuration described in the previous section. The approach integrates a simulation model developed using HOMER Grid software and focuses on optimizing the system design and EV charging schedule. By incorporating local electricity tariffs and system parameters, the method aims to minimize the Net Present Cost (NPC) while ensuring that all system constraints are met.

3.1. Simulation model development using HOMER grid

HOMER Grid is a software tool developed by the National Renewable Energy Laboratory (NREL) specifically designed for modeling and optimizing distributed energy systems, particularly for grid-tied applications [44]. It allows users to design, simulate, and optimize RE systems like solar PV systems, combined with other resources such as batteries and generators, while considering interactions with the electricity grid. Therefore, HOMER Grid was selected for this study due to its robustness, flexibility, and extensive application in energy system optimization, as

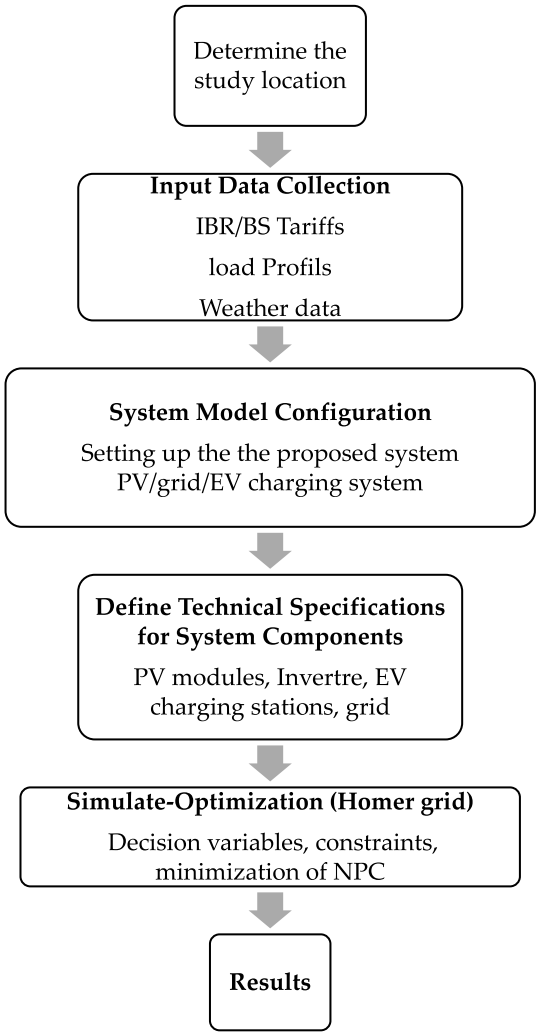

Determine the study location
Input Data Collection
IBR/BS Tariffs
load Profils
Weather data
System Model Configuration
Setting up the the proposed system PV/grid/EV charging system
Define Technical Specifications for System Components
PV modules, Invertre, EV charging stations, grid
Simulate-Optimization (Homer grid)
Decision variables, constraints, minimization of NPC
Results

Fig. 6. Flowchart of HOMER Grid simulation model development.

evidenced by its widespread use in related research for validating solution approaches [38]. The steps for the simulation modeling of energy systems (including Grid-Connected PV Systems) using HOMER Grid are represented in Fig. 6.

The process begins with input data collection and model configuration to develop a detailed simulation model using HOMER Grid Software. Accurate data collection is essential and includes capturing the household load profile, which details electricity consumption patterns with daily and seasonal variations, as well as defining the energy requirements and charging behaviors of the electric vehicle. Local solar resource data specific to Oman, including average monthly solar radiation levels, must also be integrated. The technical specifications for system components such as PV panels, and inverters are defined, encompassing their capacities, efficiencies, degradation rates, and costs. After collecting this data, it is entered into HOMER Grid to configure the model by defining component characteristics and load profiles to simulate realistic energy consumption patterns.

The accuracy and reliability of the simulation model are ensured through verification, which also checks data entry and parameter settings. We conducted verification experiments to ensure that the model operates correctly. First, we set the model to supply the household loads solely through the electrical grid without the inclusion of solar panels. This was done to verify the accuracy of the tariff input. The model's results were then compared with expected outcomes from manual calculations, and the results showed alignment. Next, we set the loads to zero for a specific month, allowing the electricity generated by the solar panels to be fully sold to the grid. The revenue calculated by the model was compared to manual calculations, and the results were consistent.

3.2. Optimization model

The optimization model aims to minimize NPC associated with configuring PV system and EV charging schedule for an Omani household. The optimization model including the decision variables, objective function, and the constraints is summarized below:

Decision variables:

P_r PV system size (kW) – the total installed capacity of PV system.
I_s Inverter capacity (kW) – the capacity of the inverter required to support the PV system.
S_{EV} EV charging schedule – number of EV charging sessions per day.

Objective function

$$\text{Minimize } NPC = \left(C_{cost} + \sum_{i=1}^{n} \frac{O_{m,i} + R_{c,i} - Rev_i}{(1+r)^i} \right) \tag{7}$$

Subject to:

$$P_r \cdot A_{panel} \leq A_{available} \tag{8}$$

$$I_S \geq P_r \tag{9}$$

$$C_{cost} \leq B_{max} \tag{10}$$

$$\frac{\sum_{t=1}^{T} X_{PV}(t)}{\sum_{t=1}^{T} E_{demand}(t)} \geq REF_{min} \tag{11}$$

$$E_{Shortage} \leq E_{Shortage-max} \tag{12}$$

$$P_r \geq 0 \tag{13}$$

$$I_s \geq 0 \tag{14}$$

$$S_{EV} \geq 0 \tag{15}$$

The objective of the model is to minimize NPC, which represents the total cost of installing and operating the PV system over its entire lifetime. The NPC includes the capital costs associated with the initial installation, ongoing operation and maintenance (O&M) costs, future replacement costs, and the revenue generated from selling excess electricity back to the grid. By minimizing the NPC, the household aims to achieve the most cost-effective energy solution.

Constraint (8) ensures that the size of the PV system P_r does not require a rooftop area that exceed the available rooftop area $A_{available}$. In this study, the available area for PV installation was determined based on the typical layout of a single-family villa-type dwelling, which is the most common residential housing form in Oman. The selected house, located within Sultan Qaboos University housing, has a rooftop area of approximately 130 m^2. In addition to the roof, an estimated 120 m^2 of useable surface is available around the garden and carport area, bringing the total installable area to around 250 m^2. Given the specifications of the SunPower E20-327 PV module—each requiring roughly 6.0 m^2 per kW of installed capacity—this surface area can accommodate up to approximately 40 kW of PV capacity. It is important to note that, due to Oman's hot desert climate, rooftops are generally not used for social or recreational purposes, unlike in some other Arab regions. Therefore, in this context, it is reasonable to assume that the entire rooftop area is available for technical applications such as solar panel installations.

Constraint (9) ensures that the inverter must be sized appropriately to handle the PV system's total output. The inverter's capacity I_S must be

equal to or greater than the size of the PV system P_r , ensuring that the system can efficiently convert solar energy from the panels into useable electricity. Constraint (10) ensures that the total capital cost of installing the system does not exceed the budget B_{max} that the household can afford. Constraint (11) ensures that the household needs to meet a specified minimum renewable energy fraction, defined as the proportion of the total energy demand that is satisfied by the PV system. This constraint ensures that a certain level of sustainability is achieved, with the household generating a minimum percentage of its energy needs from renewable sources. Constraint (12) ensures that the energy service level constraint ensures that the system can provide a reliable energy supply. It limits the total energy shortage $E_{Shortage}$, defined as the amount of energy demand that cannot be met by the system. This ensures that the household experiences a minimal shortfall in energy supply, maintaining a high level of service reliability. Constraints (13–15) provide bounds on the decision variables.

3.3. Solving the model with HOMER grid optimization algorithm

The model-solving process in HOMER Grid begins with initializing the simulation model by inputting key parameters such as load profiles, meteorological data, and system components. After configuring the PV system, inverter, and grid settings and tariffs, HOMER Grid simulates multiple scenarios to calculate electricity generation, consumption, and grid exchanges for each time step. The software then performs an economic analysis to evaluate NPC of various system configurations.

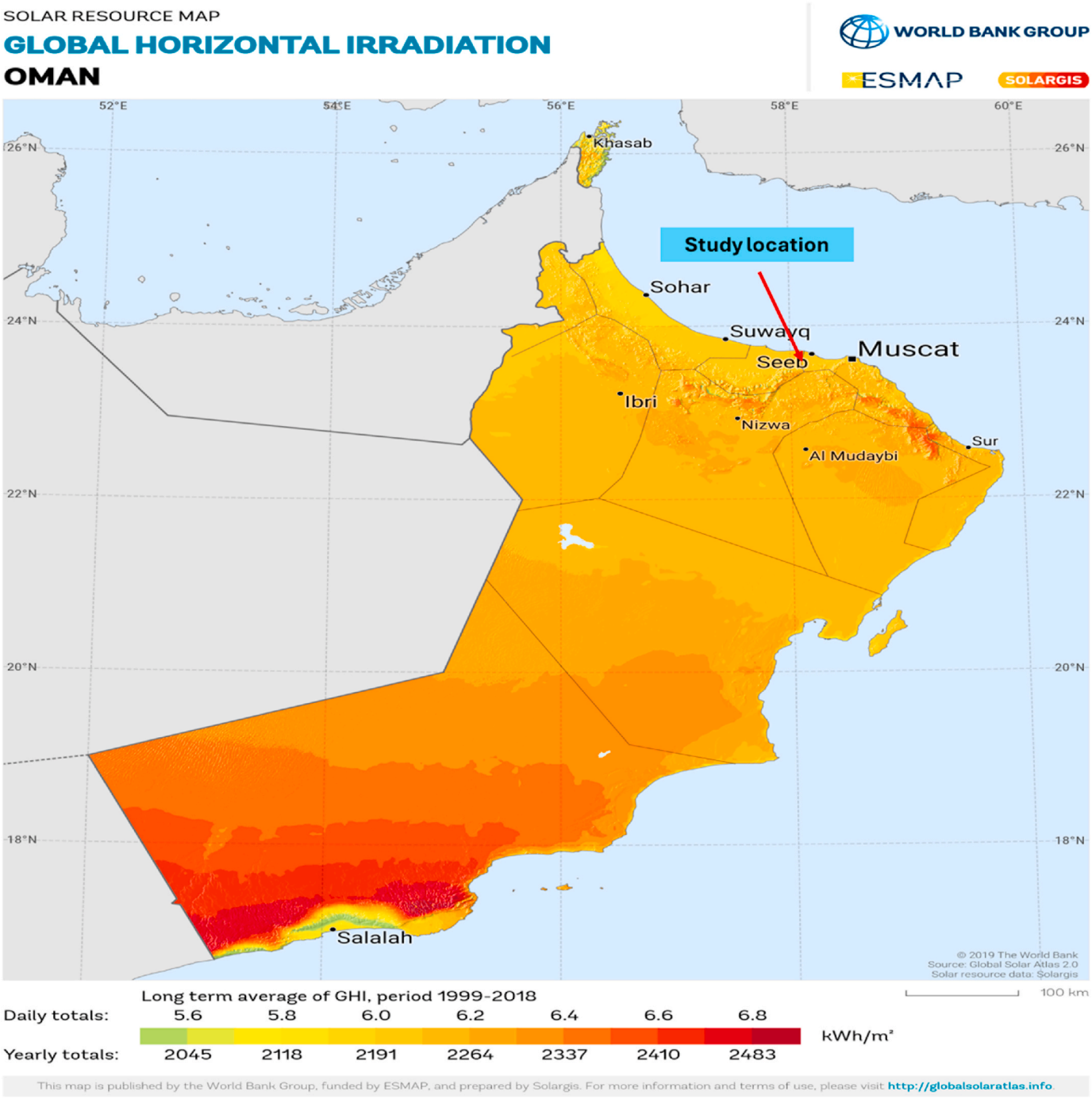


Fig. 7. Long term Global Horizontal Irradiation (GHI) map of Oman, published by the World Bank Group [45].

Through a nonlinear optimization algorithm, HOMER Grid systematically explores different combinations of decision variables, such as PV capacity, inverter size, and grid interactions, to identify the configuration that minimizes NPC while satisfying system constraints. Infeasible configurations are filtered out, and the optimal design is selected based on the lowest NPC, ensuring the system meets economic and environmental goals.

4. Results analysis

This section presents the optimization results for the system configuration and the related techno-economic performance metrics for the studied Omani household considering the current conditions and tariffs. Then, three scenarios with different sizes of the PV system are explored to assess the impact on achieving net zero energy (NZE) if the same household opts to install a larger system. Additionally, a factorial design experiment is conducted to investigate the effects and interactions of key factors—load profile, IBR tariff, BS tariff, and capital cost—on the system size and its techno-economic performance. The results provide insights into how these factors influence the optimal system design and feasibility such that useful policy implications from these results are obtained.

4.1. Data collection

This section presents the data required for conducting the different experiments highlighted above. The data are classified into two types: primary and secondary. Primary data relate to the characterization of the site and the building under consideration. This includes meteorological data, load pattern data, and electricity tariff data for the building. Secondary data consist of technical and economic assumptions about the system components, which can be summarized as follows: PV data, technical specifications, and economic data.

4.1.1. Climate and solar resource analysis

The environmental data—solar radiation, temperature, humidity, and wind speed—are very important factors that affect the performance of PV system. The house under consideration is located in the Al Khoud region (23.59° N, 58.17° E) in the Muscat governorate (see Fig. 7). Fig. 7 shows the map of Global Horizontal Irradiation (GHI) for Oman. The GHI is 5.67 kWh/m^2/day. Fig. 8 presents the average GHI for all months of the year at the building site, and clearness index, and the average temperature.

4.1.2. Base line energy consumption patterns

The selected household has three bedrooms, a living room, a reception area, three bathrooms, and a kitchen, and its electrical load is currently supplied by the national grid. The appliance categories and their power ratings are detailed in Table 4. The baseline load profile is established by collecting on-site monthly energy use data throughout the year from the house located inside Sultan Qaboos University in Muscat. The study estimates the dynamic load profile of the building by incorporating a random variability of 10 % in the electrical load. The house has an average daily demand of 50 kWh/day. Fig. 9 shows the energy consumption pattern for one month in winter (January) and one month in summer (August), considering some assumptions regarding the operating characteristics of the electrical loads (see Table 4). It is assumed that energy consumption remains constant throughout each season (summer and winter). However, the consumption does not vary between months within a season, reflecting seasonal consistency. Additionally, energy consumption is assumed to fluctuate daily within each month, accounting for day-to-day variations in energy use.

4.1.3. EV charging load

Charging technologies for Plug-in Electric Vehicles (PEVs) are classified into three levels: Level 1 uses a standard electric outlet, providing up to 8 km of range per hour and is best suited for smaller vehicles; Level 2 employs more powerful electric vehicle service equipment (EVSE) with capacities of 7–22 kW, commonly found in various locations, including homes and businesses, and can deliver up to 100 km of range per hour, making it the anticipated most common residential charging option in Oman; Level 3, or DC Fast Charging (DCFC), charges an EV to 80 % in under 30 min but is more expensive and less practical for home use, with some ultra-fast stations supporting rates up to 350 kW. This study focuses on Level 2 charging, assuming that two electric vehicles

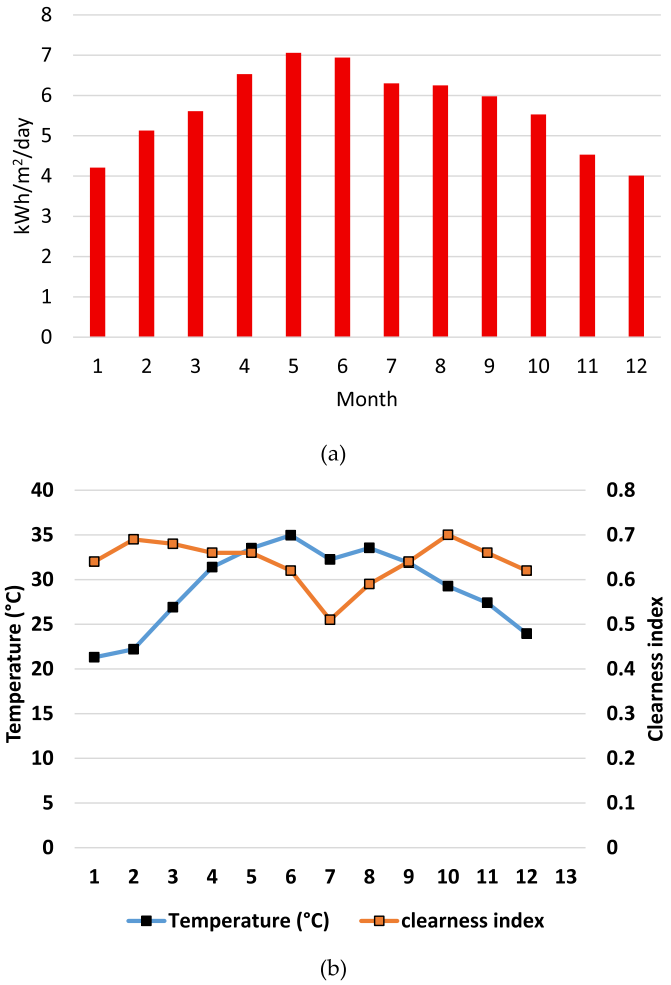
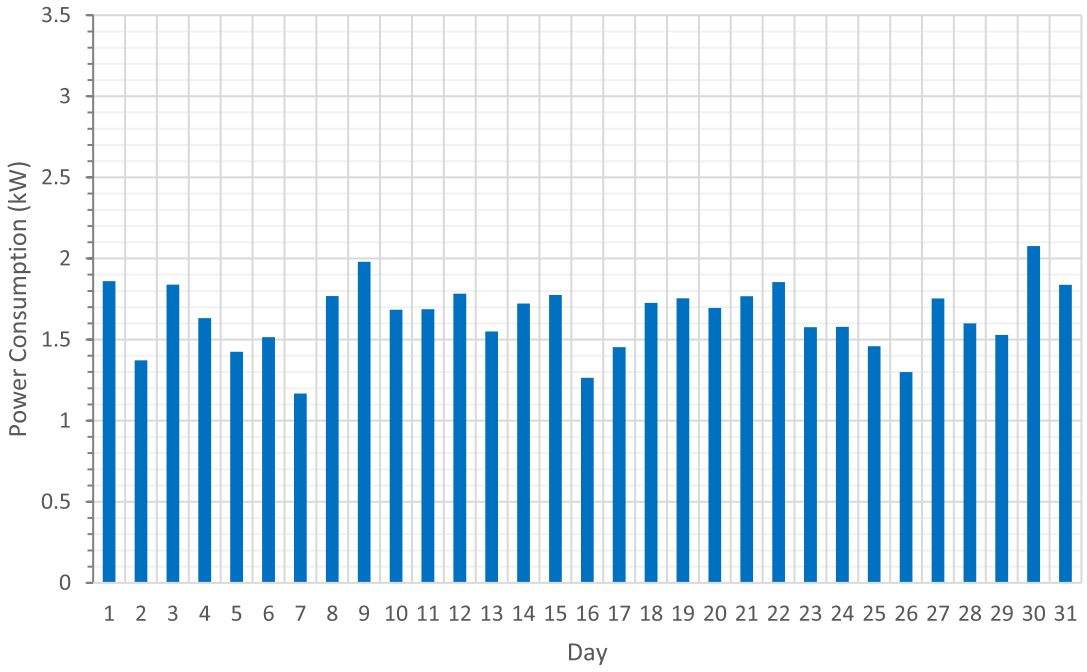


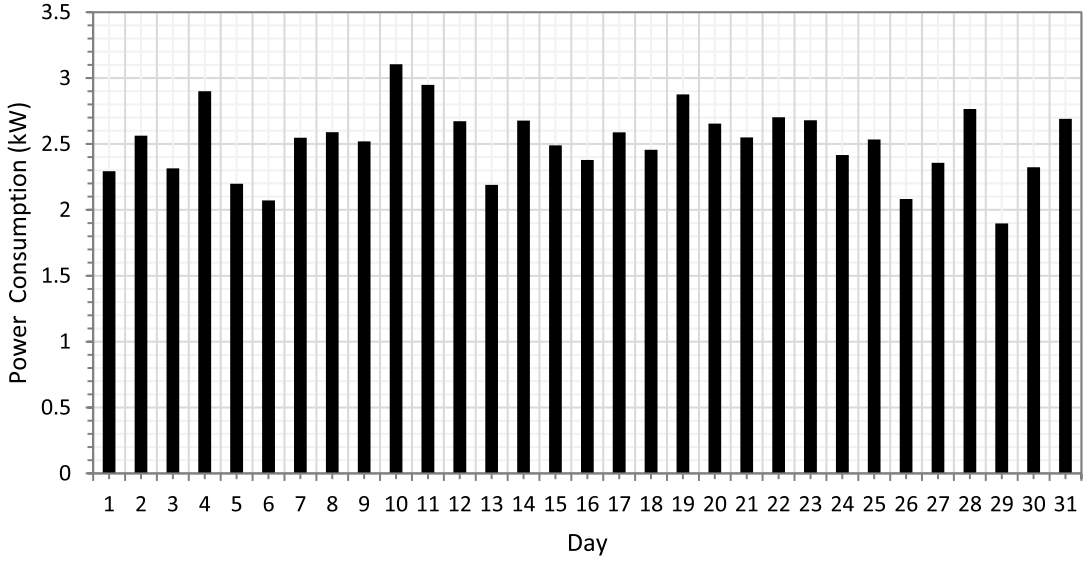
Fig. 8. (a) The monthly average (GHI), (b) Average monthly temperature and clearness index [46].

Table 4
List of typical appliances in Omani households and their power ratings.

Category	Consumption (W)	Approximate working hours per day in summer	Approximate working hours per day winter
Air condition	4000	24	0
Refrigerator	800	12	12
Cooker	3000	3	3
Iron	1200	2	2
Exhaust hood	580	4	4
Lighting	200	10	11
Laptop	320	10	10
Washing machine	2000	2	2
Cleaning machine	2000	1	1
TV	500	10	10



(a) Hourly average power consumption (kW) in January



(b) Hourly average power consumption (kW) in August

Fig. 9. The energy consumption pattern for one month in winter (January) and one month in summer (August).

Table 5
Technical data of EV level 2 charging station.

Number of EVs	2
Max charge power per EV (kW)	7.2
Charger output power (kW)	15
No. of charger	2
Scaled avg sessions/day	2
Required charging energy per EV	64

will be charged during the day, with Table 5 providing the technical details for the HOMER Grid and an estimated average daily EV charging load of 97 kWh/day, while Fig. 10 illustrates the yearly charging load profile.

4.1.4. Technical and economic data

Table 6 presents the technical and economic details of the PV system considered in this study, including the costs associated with each component. The PV system uses the SunPower E20-327 model, which has a rated capacity of 327 W per module. This model features a derating factor of 0.85 and has a lifespan of 25 years. The capital cost of the module is $0.88 per watt, and the replacement cost is equal to 100 % of the capital cost. The annual operation and maintenance (O&M) cost for the module is $23/kW/year. The converter used in the system is the Kaco Blueplanet 10.0 TL3, which has a 15-year lifespan and an efficiency of 97 %. The capital cost of the converter is $300 per kW, and the

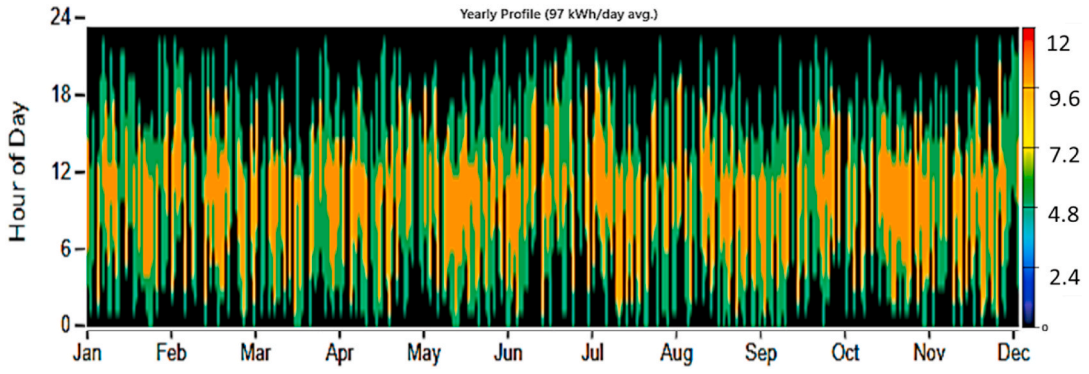


Fig. 10. EV charging load yearly profile.

Table 6
Technical and cost details including the costs of each component [47].

Item	Value
PV	
Model	Sun power E20-327
Rated capacity PV module	327 W
Derating factor	0.85
Life time	25 years
capital cost	0.88$/watt
Replacement cost	100 % of capital cost
O&M cost per kW	23 $/year
Converter	
Model	Kaco – blueplanet 10.0 TL3
Life time	15
Efficiency	97 %
Capital cost per kW	300 $
Replacement cost	100 % of capital cost

replacement cost is also 100 % of the capital cost.

4.2. Optimal system configuration for the considered household

The simulation-optimization approach has been applied to determine the optimal design and operation of the PV system integrated with an EV charging station for the Omani household, based on the technical, environmental, and cost data outlined in the previous section. The settings of HOMER Grid's optimization algorithm were adjusted through preliminary experiments to enhance the algorithm's performance for the cases considered in this research.

The optimization results indicate that the baseline system, relying solely on the utility grid, achieves the lowest net present cost when meeting the household's total electricity demand of 54 MWh/year, which includes both the baseline load and the EV charging load. Although the proposed RE system, combining solar PV with the utility grid, is designed to increase RE penetration and reduce environmental impact, the economic analysis shows that the baseline system is the most cost-effective option under the modeled conditions. This is largely due to the low IBR tariff rates in Oman, which make grid reliance more affordable than investing in RE systems. Consequently, while solar PV could offer environmental benefits, the financial advantage of the baseline system under current tariff structures may hinder the widespread adoption of RE in the residential sector of Oman.

For further analysis, three alternative grid-connected RE systems of 20 kW, 30 kW, and 40 kW were analyzed based on available household space, as shown in Table 7. The optimization model was specifically adjusted to restrict the PV system size in each scenario to the respective predetermined sizes while focusing on minimizing the net present cost. Consequently, the optimization model was constrained to these specific system sizes. The baseline scenario, relying solely on the utility grid, demonstrated a lower NPC of $27.5k compared to the RE system configurations, which had NPCs of $36.9k, $40.5k, and $45.9k for the 20 kW, 30 kW, and 40 kW systems, respectively. Although the 40-kW system produced the highest energy output of 89.6 MWh/year and achieved RE fraction of 78.3 %, its NPC was the highest among the options. However, it provided significant utility bill savings of $3882 annually and had the shortest payback period of 22 years. Additionally, the 40-kW configuration resulted in net negative CO_2 emissions of −14.03 tons per year, contrasting with the 26.4 tons emitted by the grid-only system.

5. Factorial analysis

5.1. Investigated factors

The optimal system design and the economic viability of RE systems can be influenced by various technical and economic factors. In this section, we investigate the factors that can impact the optimal size of a grid-connected PV system integrated with EV charging station for Omani households. This factorial design experiment aims to investigate the influence of four key factors—Energy Demand (Load Profile), IBR Tariff, BS Tariff, and Capital Cost—on the optimal design and techno-economic feasibility of the energy system. Factorial design is a systematic method used in experimental research to evaluate the effects of multiple factors

Table 7
Techno-Economic results for different scenarios of the system configuration.

Configuration	Grid- 20 kW PV	Grid- 30 kW PV	Grid- 40 kW PV	Grid (base case)
Energy Production (MWh/yr)	35.84	53.76	89.60	0
Energy Purchase (MWh/yr)	31.16	26.35	22.87	54.0
Energy Sold (MWh/yr)	10.20	22.01	51.20	0
Ren Frac %	51.3	65.3	78.3	0
NPC (k$)	36.9	40.5	45.9	27.5
LCOE ($/kWh)	0.0424	0.0393	0.0321	0.0376
Utility bill saving ($/yr)	1400	2187	3882	0
Net utility bill saving ($/yr)	19023	29727	52768	0
Payback time (yr)	25	24	22	–
CO_2 emission ton/yr	10.268	2.124	−14.03	26.4

Table 8
The investigated factors and their respective levels.

Factor	Low (L)	Base (B)	High (H)
IBR Tariff	−50 %	0 %	50 %
BS Tariff	−50 %	0 %	50 %
Load Profile	−50 %	0 %	50 %
Capital Cost	−50 %	0 %	50 %

(independent variables) on one or more response variables. In a factorial design, each level of each factor is combined with every level of all other factors, creating a comprehensive set of experimental conditions. In this research, the performance metrics evaluated include the optimal PV system size and NPC. A full factorial design with three levels for each factor is employed, leading to a total of 81 experimental runs ($3^4 = 81$). The factors and their respective levels are provided in Table 8. The base level for each factor is set using the original experiment's data (presented in the previous section), while the low and high levels are adjusted by decreasing and increasing the baseline by 50 %, respectively.

To conduct the experiments, the four factors were selected based on their potential impact on the PV system size and its techno-economic feasibility for Omani households. For each experimental run, the simulation-optimization approach is employed to determine the optimal sizing of the energy system, facilitating the calculation of the techno-economic metrics for each combination of factors levels.

The results of these experimental runs are presented in Figs. 11–12, allowing for a comprehensive analysis of how variations in the investigated factors influence the optimal system size and net present cost. The analysis involves generating main and interaction effect plots to visually represent the influence of each factor and their combinations on the performance metrics. This allows for an in-depth understanding of how changes in one factor may impact the outcomes associated with other factors. The results reveal critical insights into the influence of IBR tariff, BS tariff, Load Profile, and Capital Cost on the techno-economic feasibility of the energy system. The results indicate that all the investigated factors affect the performance metrics included in this factorial design experiment (see Figs. 11–12). Below, the impact of the investigated

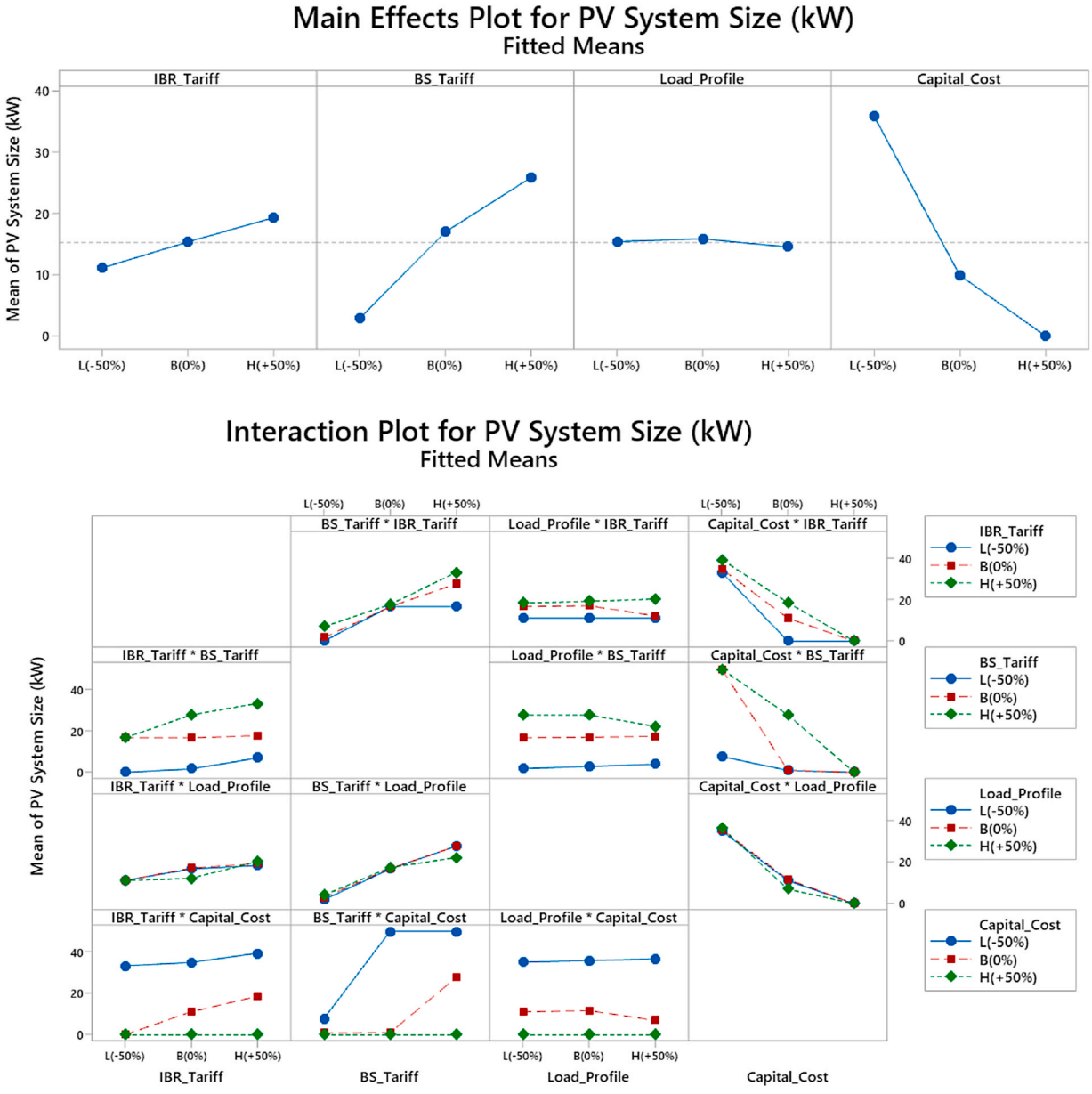


Fig. 11. The effects of the investigated factors on the optimal PV system size.

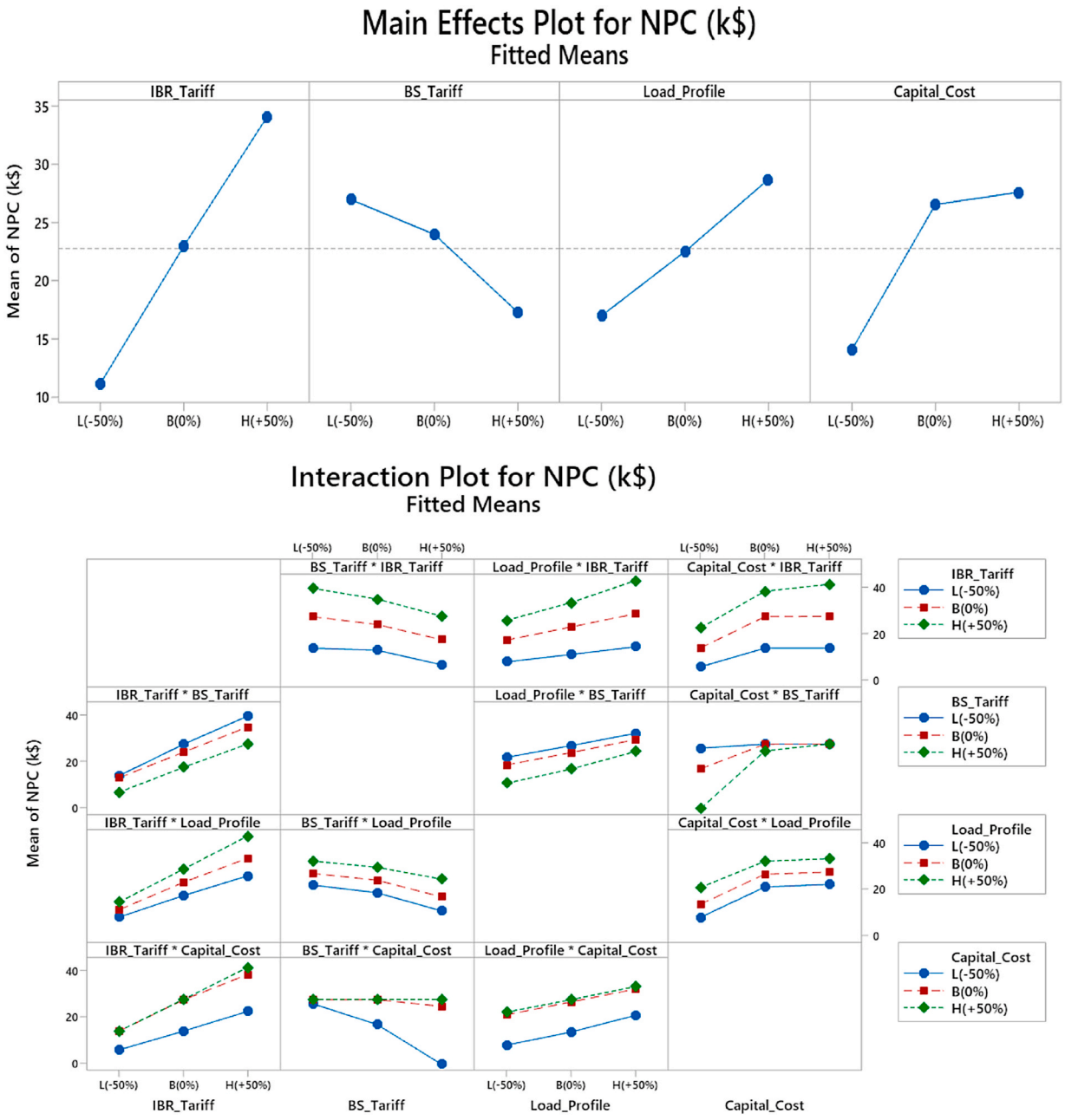


Fig. 12. The effects of the investigated factors on the net present cost.

factors on optimal PV system size and NPC is discussed.

5.2. The impact of the IBR tariff

The results reveal that as the IBR tariff level increases from the Base tariff (the currently employed tariff in Oman) to the high level (+50 %), the mean PV system size increases from about 15 kW to 20 kW (see Fig. 11). However, if the IBR tariff decreases from the base tariff to the low level (−50 %), the mean PV system size decreases from about 15 kW to 10 kW, which indicates the reliance on the grid will increase because installing PV systems with large sizes will not be economical for the Omani households in such case. This factor also significantly influences the net present cost (see Fig. 12). The results also indicate that the effect of the IBR tariff is sensitive to the levels of the other factors (BS Tariff, Load Profile and Capital Cost). This suggests that the current IBR tariff may need to be adapted to enhance the techno-economic feasibility of PV systems for Omani households. The results of the original case (based on the base levels for all factors) indicated that the optimal solution favored supplying the household's energy demand from the grid, implying that minimizing net present cost relies more on grid dependency rather than the installation of PV systems. However, the results of the factorial experiments, which account for different scenarios, indicate that increasing the pricing rates of the IBR tariff will encourage a higher mean PV system size.

5.3. The impact of the BS tariff

The results show that as the BS tariff level increases from the Base tariff (the currently employed tariff in Oman) to the high level (+50 %), the mean PV system size increases significantly. However, if the BS tariff decreases from the base tariff to the low level (−50 %), the mean PV system decreases, which indicating that the tariff will make that installing PV systems within Omani households not economically feasible compared to relying on the national grid. This can also be

inferred from the results related to the impact of the BS tariff on the other economical metrics such as NPC where the value of this metric decreases as the BS tariff increases while itsvalue increases as the BS tariff decreases. The results also indicate that the effect of the IBR tariff is sensitive to the levels of the other factors (IBR tariff, Load profile and Capital cost). These results indicate that increasing the rates of the current BS tariff employed in Oman will make it suitable for adopting PV system within Omani households, and thus decreasing the reliance on the national grid.

Several strategies can be adopted to enhance the use of surplus PV electricity [48]. One approach is to adapt the current BS tariff in Oman to encourage households to install integrated energy systems with EV charging for self-consumption, and utilizing net metering to provide financial incentives for surplus energy exported to the grid. Net metering, in particular, can help reduce electricity bills, especially if an IBR tariff is applied, as the consumer will be charged lower rates for the electricity they consume from the grid, and receive credit for the surplus energy they export [49]. Another strategy involves incorporating energy storage systems, such as thermal or battery storage, to store excess electricity for later use, reducing grid dependency. Optimizing household appliance scheduling within smart energy systems can also help maximize self-consumption by aligning appliance use with peak PV generation times. These strategies require further investigation to assess their viability in Oman, considering local conditions, regulations, and market dynamics.

5.4. The impact of the load profile

Th results indicate that the mean PV system size is not affected by the change in the load profile level. However, the results show that interaction effect might exist between the load profile and other factors including IBR tariff, BS tariff and Capital cost. For low and high levels of capital cost, the mean PV system size is not affected by the change in the load profile level. However, at the base capital cost, the mean PV system size decreases as the load profile level increases from the base level to the high level. Similarly, at the high level of the BS tariff and the Base level of the IBR tariff, the mean PV system size decreases as the load profile level increase. However, the impact of the load profile on NPC seems to be consistent where the NPC increases as the load profile level increase while the interaction effect of the load profile with other factors is almost negligible which means that the main effect can be valid regardless of the levels of other factors.

5.5. The impact of the capital cost

The results indicate that the mean PV system size will be affected by the change of the level of capital cost as the system size decreases considerably as the capital cost increases. It can be observed that if the level of the capital cost increases from the base level to the high level, the mean PV system size decreases while the mean PV system size increases considerably as the capital cost decreases by 50 %. Therefore, a key driver for large installation within Omani households is to develop policies that affect the capital cost of PV systems and other relevant components.

These findings are particularly important in the context of Oman's ongoing electricity subsidy reform. By varying the IBR and BS tariffs across ±50 % of their current values, this factorial design effectively emulates future cost-reflective tariff scenarios anticipated under Vision 2040. This enables the identification of threshold conditions under which PV-EV systems become economically attractive, providing valuable insights for decision-makers regarding tariff restructuring and support mechanisms.

5.6. Comparison of the study to benchmark existing research

As reported earlier in Table 1, benchmarking of previous studies has been conducted to investigate the techno-economic aspects of renewable energy systems integrated with EV charging systems for residential applications. Khan et al. [14] investigates PV-grid solar systems for residential buildings in Australia, addressing home charging and utility bill savings but neglecting tariff, load profile, and capital cost effects. The study demonstrated a payback period of 4.46 years and an LCOE of 0.074 AUD/kWh. Khan et al. [15] adds battery storage to PV-grid systems while retaining a focus on residential buildings in Malaysia but also overlooks critical economic and technical aspects. The study found that a grid-connected system without batteries achieved the lowest LCOE of 0.16 RM/kWh. Al-Buraiki et al. [34] diversifies energy sources with PV, wind turbines, and batteries for residential houses in Saudi Arabia, considering home charging but omitting the analysis of tariff, load profile, and capital cost impacts. The study demonstrated that the lowest LCOE achieved was $0.4381/kWh. In contrast, the current work in Oman stands out by focusing on PV-grid solar systems specifically for residential charging stations, addressing home charging, utility bill savings, IBR and BS tariff effects, as well as load profile and capital cost impacts. The analysis revealed that IBR and BS tariffs significantly influence PV system sizing, whereas load profiles have a minimal impact. Furthermore, higher capital costs reduce the optimal size of PV systems. This comprehensive analysis fills significant gaps in the literature, particularly by integrating a detailed economic evaluation and focusing on the practical application of residential EV charging stations, making it a valuable contribution to renewable energy research in Oman.

6. Conclusion

This paper investigates the techno-economic feasibility of integrating photovoltaic (PV) systems with electric vehicle (EV) charging stations for Omani households. We detail the relevant energy system, including currently applied electricity tariffs and the associated decision-making problem related to the design and operation of such systems. A simulation-optimization approach utilizing the HOMER Grid tool, alongside a tailored optimization model for the Omani households, was introduced.

Our results indicate that the baseline system, which relies solely on the utility grid, has the lowest Net Present Cost (NPC) for a household with an electricity demand of 54 MWh/year, encompassing both baseline and EV charging loads. Despite the intention to increase renewable energy penetration through the proposed solar PV and grid combination, the low inclining block rate (IBR) tariffs in Oman make grid reliance more economical than investing in PV systems. Further analysis of alternative grid-connected renewable energy systems (20 kW, 30 kW, and 40 kW) revealed that the baseline system's NPC is $27.5k, compared to $36.9k, $40.5k, and $45.9k for the respective PV systems. While the 40 kW system yields the highest energy output and annual utility bill savings of $3,882, it also incurs the highest NPC and results in net negative CO2 emissions of −14.03 tons per year, in contrast to the emissions from the grid-only system.

This research examined factors influencing the optimal design and economic viability of grid-connected PV systems with integrated EV charging stations for Omani households. Instead of adopting an international tariff structure, the study incorporates local IBR and BS tariff variations through factorial analysis, enabling a realistic evaluation of how Oman's planned electricity pricing reforms could improve the techno-economic feasibility of residential PV-EV systems. A factorial design experiment analyzed the impacts of energy demand (load profile), IBR tariff, BS tariff, and capital cost on optimal system size and NPC. The findings revealed that all factors significantly affect performance metrics: increasing IBR and BS tariffs encouraged larger PV system sizes, while higher capital costs led to smaller systems. Although the load profile had minimal direct impact, it interacted with other factors. In summary, the optimal design of grid-connected PV systems integrated with EV charging stations for Omani households is significantly influenced by key factors such as energy demand, IBR tariff, BS tariff, and

capital cost. Adjustments to these factors can enhance the techno-economic feasibility of renewable energy systems, encouraging broader adoption among households. Specifically, increasing IBR and BS tariffs can promote larger PV system installations, while lower capital costs are essential for improving economic viability. Furthermore, integrating renewable energy solutions can address challenges related to electric vehicle charging infrastructure, reduce reliance on fossil fuels, and contribute to lower carbon emissions.

Integrating renewable energy systems into households can address challenges associated with electric vehicles, such as insufficient public charging infrastructure, while reducing reliance on fossil fuels and lowering carbon emissions. However, widespread adoption requires government support, including cost-reduction incentives and increased compensation for surplus electricity exported to the grid. Policymakers must address these challenges to promote sustainable energy solutions and meet both energy and charging infrastructure needs effectively. Future research should focus on investigating different configurations of hybrid renewable energy systems and on designing tariff structures that effectively support the adoption of residential renewable energy systems integrated with EV charging in the Omani context. In addition, future studies could explore the feasibility of surplus PV electricity management strategies specific to Oman, while also evaluating alternative electricity pricing mechanisms—including internationally or regionally applied models such as time-of-use (TOU) tariffs and IBR tariffs coupled with net metering. Such investigations would offer broader insights into the techno-economic potential of PV-EV systems under diverse regulatory and market conditions.

CRediT authorship contribution statement

Suzan Abdelhady: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Nasr Al-Hinai:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Investigation, Data curation, Conceptualization. **Ahmed Shaban:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

All data is available from the corresponding author upon request.

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